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SUMMARY

For fixed satellite communication systems at Ka band with downlink at 17.7 to 20.2 GHz and uplink at 27.5 to 30.0 GHz, the focused optics and the unfocused optics configurations with monolithic phased array feeds have often been used to provide multiple fixed and multiple scanning spot beam coverages. It appears that a dual frequency microstrip antenna capable of transmitting and receiving simultaneously is highly desirable as an array feed element. This paper describes some early efforts on the development and experimental testing of a dual frequency annular microstrip antenna. The antenna has potential application for use in conjunction with a monolithic microwave integrated circuit device as an active radiating element in a phased array of phased array feeds. The antenna is designed to resonate at TM_{12} and TM_{13} modes and tuned with a circumferential microstrip ring to vary the frequency ratio. Radiation characteristics at both the high and low frequencies are examined. Experimental results including radiating patterns and swept frequency measurements are presented.

INTRODUCTION

Microstrip antennas are attractive as radiating elements for space communication systems because of their inherent advantages of compact structure, weight and cost. Dual frequency microstrip antennas have the additional feature that a single antenna element can transmit or receive in two discrete bands simultaneously. The research on dual frequency microstrip antenna has been extensive, and many different configurations have been described (refs. 1 and 2). However most of the work reported thus far are for low frequency applications. Recently, a hybrid multiport theory for analyzing these antennas has been developed (ref. 3). Theoretical results based on this theory are found to be in excellent agreement with measured results.

The annular microstrip antenna appears uniquely suited for dual frequency application. Unlike rectangular microstrip antennas, the resonant frequencies of such antennas are not harmonically related. Thus, the frequency ratio of any two modes can be varied by choosing the inner and outer radii. In addition, higher gain and easier matching can be achieved, for the size of the annular microstrip is generally larger than the rectangular microstrip antenna at Ka band.

This paper describes some early efforts on the design and experimental testing of dual frequency annular microstrip antennas at Ka band. Preliminary experimental results for a single annular microstrip antenna and a 2 by 2 microstrip array are presented. No attempt has been made to optimize the antenna performance. Thus, the results obtained thus far primarily established the feasibility of this approach and the potential for future improvement.

Annular Microstrip Antenna Design

Based on a radial cavity model for a thin microstrip antenna and with the application of the usual magnetic wall boundary conditions, the resonant frequency of an annular microstrip antenna, as pictured in figure 1, can be computed from the characteristic equation for the resonant modes (ref. 4):

$$J_n'(ka)Y_n'(kb) - J_n'(kb)Y_n'(ka) = 0$$

$$\text{with} \quad k = \frac{\omega}{c}\sqrt{\epsilon_d}$$

where a and b are the inner and outer radii respectively; ω is the resonant radian frequency; c is the speed of light, and ϵ_d is the relative dielectric constant of the substrate. The quantities $J_n'(x)$ and $Y_n'(x)$ are the derivatives of the Bessel functions of the first and second kind of order n respectively. The integer n is the azimuthal mode number.

To design the annular microstrip antenna for dual frequency operation, the high and low frequency bands are chosen to satisfy the design requirements of polarization, frequency ratio, antenna dimension and input impedance. In general, the antenna dimension and the resonant frequencies can be easily determined by computing the roots of the characteristic equation for any given radii a and b. However, a more rigorous analysis (ref. 3) must be applied for accurate prediction of the input impedance and radiation patterns.

It has been reported (refs. 5 and 6) that the TM_{12} mode of the annular microstrip antenna has relatively wide bandwidth and hence is more suitable for antenna applications. Based on this information, the TM_{12} and TM_{13} modes have been chosen as operating modes for the Ka band. In order to illustrate the frequency separation between different modes with respect to antenna radii a and b, the resonant frequencies for the lower-order modes of the annular microstrip antenna have been computed numerically using the iteration technique. The results are plotted in figures 2 and 3 as a function of b/a, the ratio of outer radius to inner radius. Figure 2 shows the resonant frequencies of the lower-order modes as a function of b/a with a = 0.1 cm and b varied; figure 3 shows the same with b = 0.9 cm and a varied. As demonstrated graphically, the variation of the outer radius b produces a greater impact on the resonant frequencies as compared to the inner radius a. With the radii a and b properly chosen, it appears that the frequency requirement for dual frequency operation at Ka band can be satisfied with little frequency tuning required. The resonant frequencies for the TM_{12} and the TM_{13} mode and their corresponding frequency ratio for various radii a and b are tabulated in table 1. From these tabulated results, the following observations are made: (1) the frequency ratios decrease with increasing b/a, (2) for cases considered, the frequency ratio is found to be around 1.6, and (3) by holding the inner radius constant, the resonant frequency generally decreases with an increase in the center radius b.

EXPERIMENTAL RESULTS

Based on results of table 1, a single annular microstrip antenna with an inner radius a = 0.1 cm and an outer radius b = 0.93 cm has been fabricated and experimentally tested. Table 2 compares the calculated and the measured resonant frequencies for the TM_{12} and the TM_{13} modes. As shown, the resonant frequencies predicted by the characteristic equation agree reasonably well with the experimentally measured values. The deviation between the calculated and the measured values is found to be about 3 %. The swept frequency measurements for the two frequency bands are displayed in figures 4 and 5. These results clearly demonstrate the feasibility of dual frequency operation at Ka band with a single antenna. The corresponding radiation patterns for the same antenna are shown in figures 6 to 9.

A 2 by 2 microstrip array of identical radiating elements as described above has been fabricated and experimentally tested. The spacing between elements is 2 cm. The array is tested with a symmetric microstrip power dividing network. The radiation patterns for the high and the low frequency bands are shown in figures 10 to 13.

The usefulness of the dual frequency microstrip antennas is greatly enhanced if the frequency ratios can be varied over a wide range. In fact, the bandwidth of the microstrip antenna can be broadened if the two discrete bands of the high and low frequencies has a frequency ratio approaching unity. There exist three well established techniques for frequency tuning. Using these techniques, the frequency ratio of a rectangular microstrip antenna has been effectively reduced to about 1.07 at x-band frequencies or less (ref. 7). Because of the small antenna size at Ka band, frequency tuning of the annular microstrip antenna has been attempted using a circumferential microstrip line. This technique has been found very effective for the TM_{12} mode, but less effective for the TM_{13} mode. Experimental results illustrating frequency tuning of an annular microstrip antenna are shown in figure 14.

CONCLUSION

Preliminary experimental data demonstrate that an annular microstrip antenna can be designed for dual frequency operation at Ka band. By properly choosing the inner and the outer radii of the antenna, a frequency ratio of approximately 1.6:1 between the high and the low frequency bands can be achieved. The resonant frequency of the TM_{12} mode can be varied over a range of about 1 GHz with a circumferential microstrip line. Further improvement in the antenna performance is possible with better impedance matching and more effective frequency tuning of the TM_{13} mode.

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TABLE 1. - RESONANT FREQUENCIES FOR TM_{12} AND TM_{13} MODES VERSUS ANTENNA RADII a AND b (ϵ_r = 2.1)

(a) a fixed, b varied

a	b	b/a	f_{12}	f_{13}	f_{13}/f_{12}
0.1	0.75	7.5	22.2	35.9	1.62
0.1	0.80	8.0	20.9	33.7	1.61
0.1	0.85	8.5	19.7	31.7	1.60
0.1	0.90	9.0	18.7	29.9	1.60
0.1	0.95	9.5	17.7	28.4	1.59
0.1	1.00	10.0	16.9	27.0	1.59

(b) b fixed, a varied

0.06	0.9	15.00	19.2	30.5	1.58
0.08	0.9	11.25	18.9	30.1	1.59
0.10	0.9	9.00	18.7	29.9	1.60
0.12	0.9	7.50	18.5	29.9	1.62
0.14	0.9	6.40	18.3	30.1	1.64

Table 2. - CALCULATED AND MEASURED RESONANT FREQUENCIES FOR THE ANNULAR MICROSTRIP ANTENNA (a = 0.1 cm, b = 0.93 cm, ϵ_r = 2.2)

Modes, m,n	Calculated resonant frequency, GHz	Measured resonant frequency, GHz	Deviation, percent
(1.2)	17.7	17.4	1.7
(1.3)	28.3	29.2	3.0

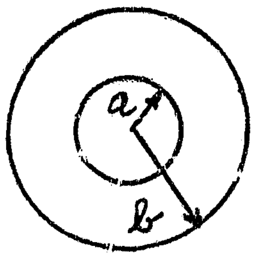

Figure 1. - Annular microstrip antenna.

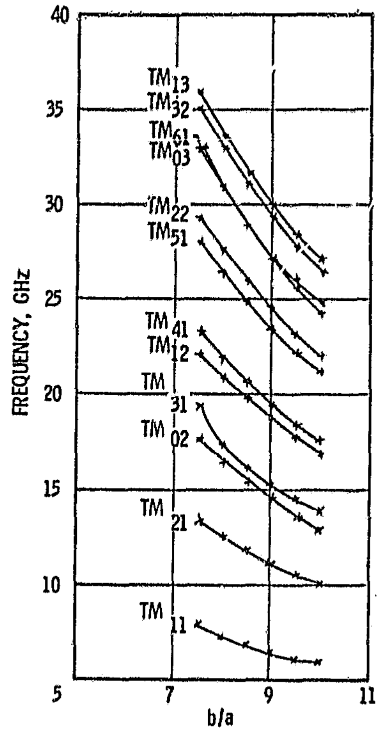

Figure 2. - Resonant frequencies vs b/a with a = 1 cm and b varied.

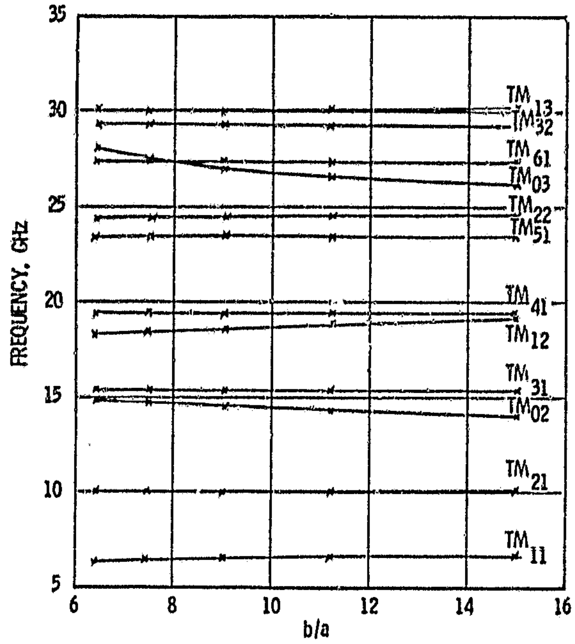

Figure 3. - Resonant frequencies vs b/a with b = .9 cm and a varied.

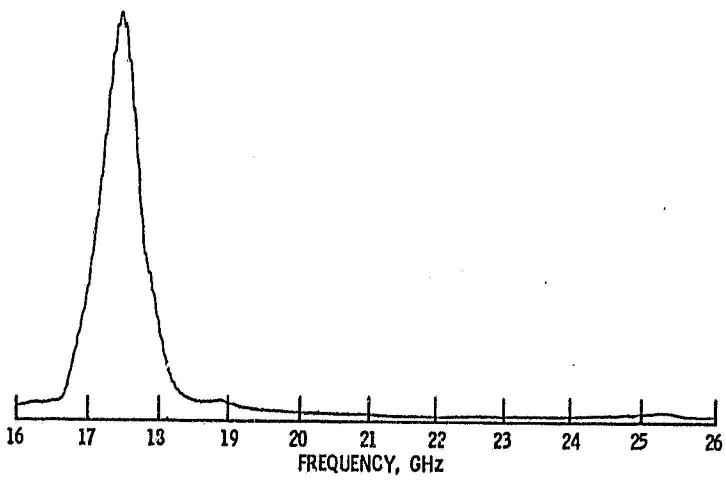

Figure 4. - Relative power vs frequency for an annular microstrip antenna. (Low band).

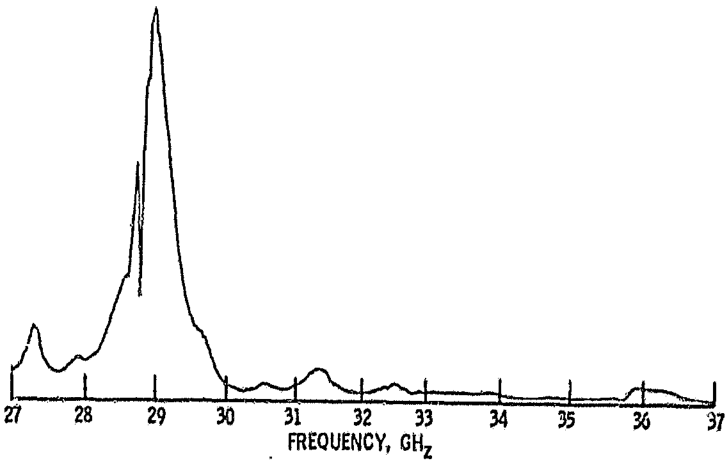

Figure 5. - Relative power vs frequency for an annular microstrip antenna. (High band).

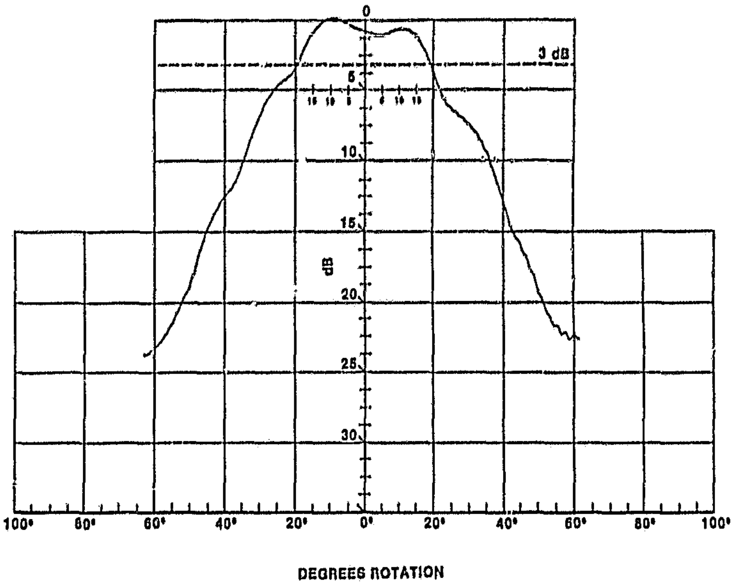

Figure 6. - H - plane radiation pattern of an annular microstrip antenna (f = 17.4 GHz).

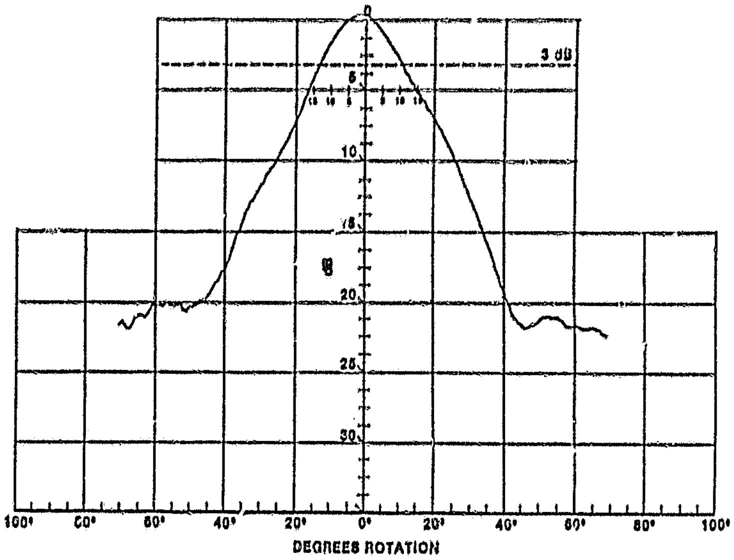

Figure 7. - E - plane radiation pattern of an annular microstrip antenna (f = 17.4 GHz).

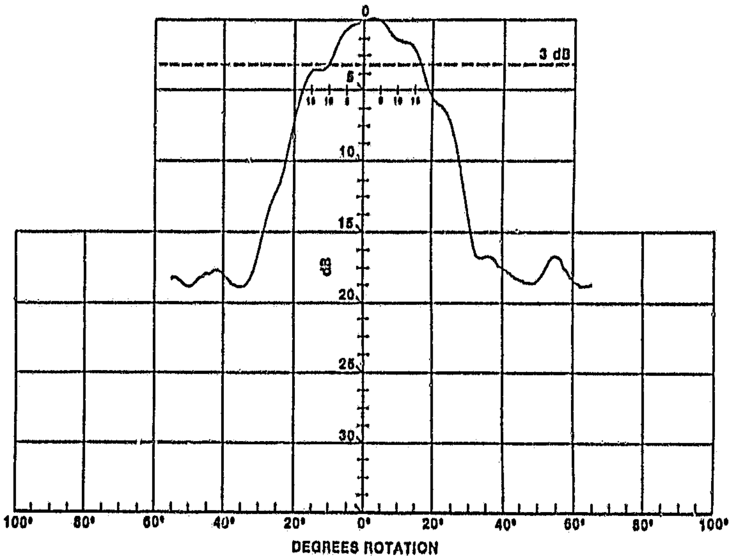

Figure 8. - H - plane radiation pattern of an annular microstrip antenna (f = 29.2 GHz).

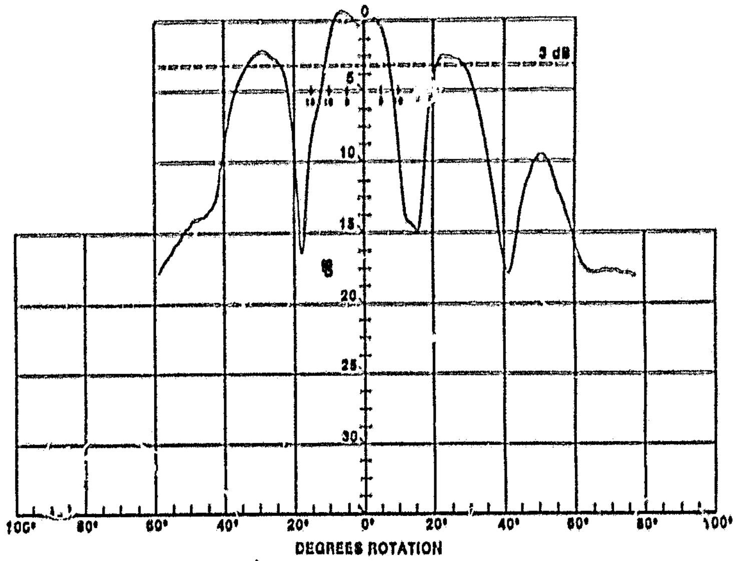

Figure 9. - E - plane radiation pattern of an annular microstrip antenna (f = 29.2 GHz).

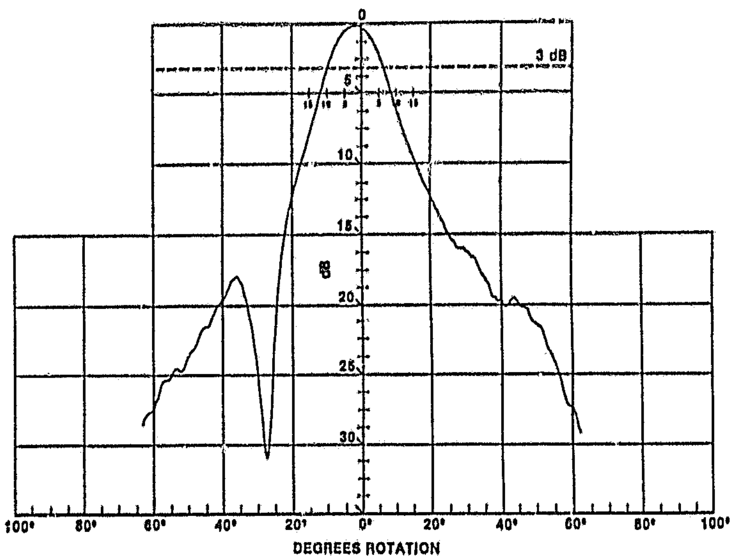

Figure 10. - H - plane radiation pattern of a 2x2 annular microstrip array (f = 17.4 GHz).

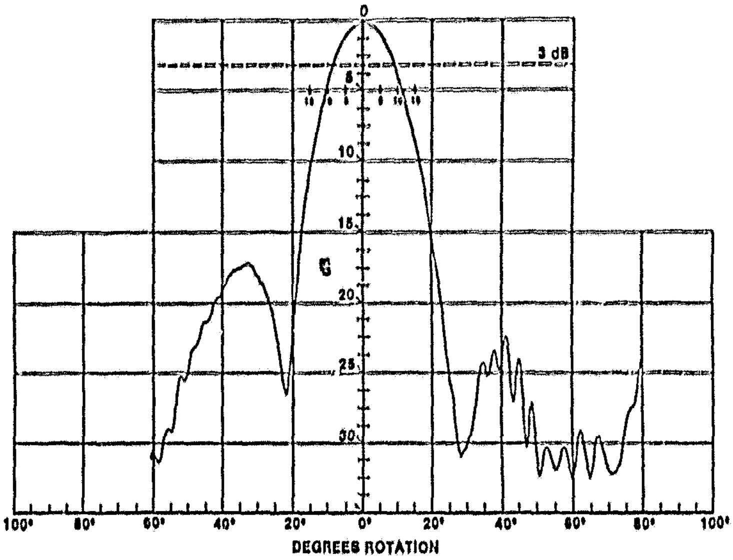

Figure 11. - E - plane radiation pattern of an 2x2 annular microstrip array (f = 17.4 GHz).

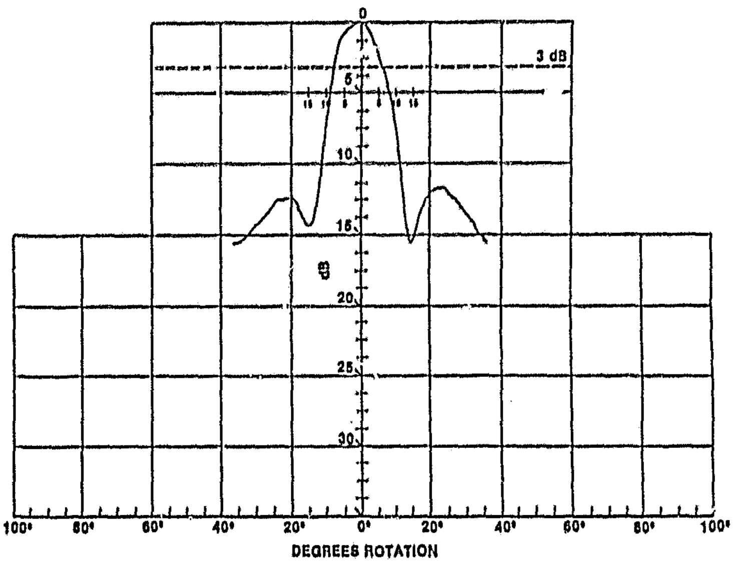

Figure 12. - H - plane radiation pattern of a 2x2 annular microstrip array (f = 29.2 GHz).

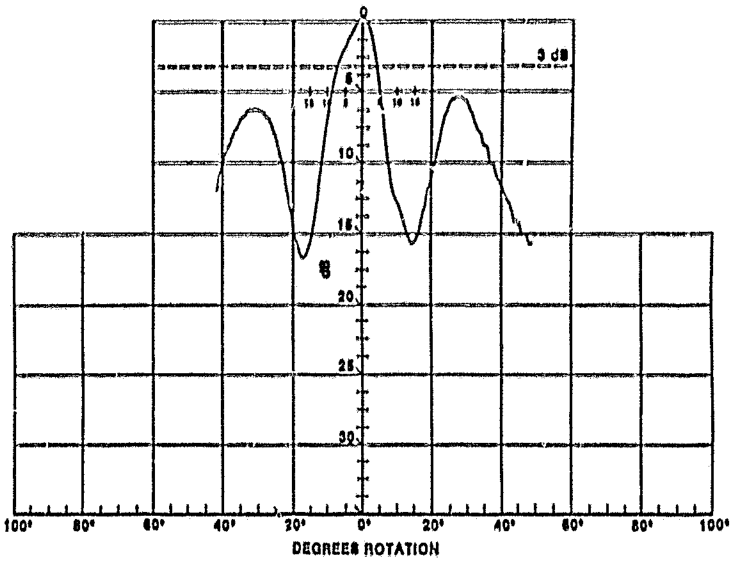

Figure 13. - E - plane radiation pattern of a 2x2 annular microstrip array (f = 29.2 GHz).

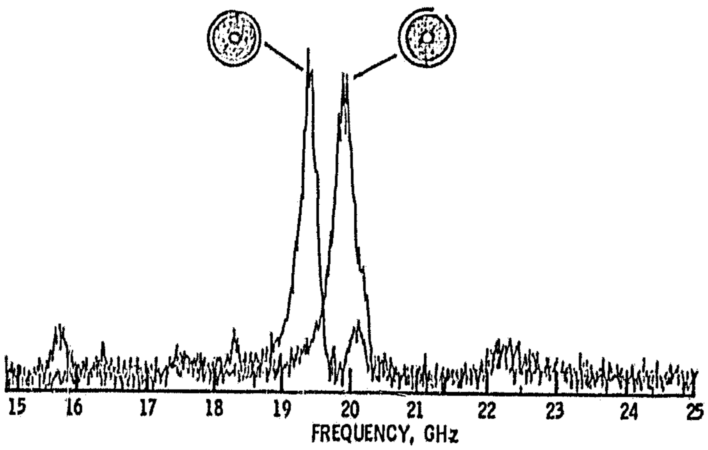

Figure 14. - Frequency tuning of an annular microstrip antenna.

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15. Supplementary Notes

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16. Abstract

For fixed satellite communication systems at Ka band with downlink at 17.7 to 20.2 GHz and uplink at 27.5 to 30.0 GHz, the focused optics and the unfocused optics configurations with monolithic phased array feeds have often been used to provide multiple fixed and multiple scanning spot beam coverages. It appears that a dual frequency microstrip antenna capable of transmitting and receiving simultaneously is highly desirable as an array feed element. This paper describes some early efforts on the development and experimental testing of a dual frequency annular microstrip antenna. The antenna has potential application for use in conjunction with a monolithic microwave integrated circuit device as an active radiating element in a phased array of phased array feeds. The antenna is designed to resonate at TM_{12} and TM_{13} modes and tuned with a circumferential microstrip ring to vary the frequency ratio. Radiation characteristics at both the high and low frequencies are examined. Experimental results including radiating patterns and swept frequency measurements are presented.

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